# Identifying microstructural features in unidirectional composite tapes

Katuin, N.; Peeters, D.M.J.; Dransfeld, C.A.

**Publication date**
2022

**Document Version**
Final published version

**Published in**
Proceedings of the 20th European Conference on Composite Materials: Composites Meet Sustainability

**Citation (APA)**
Katuin, N., Peeters, D. M. J., & Dransfeld, C. A. (2022). Identifying microstructural features in unidirectional composite tapes. In A. P. Vassilopoulos , & V. Michaud (Eds.), *Proceedings of the 20th European Conference on Composite Materials: Composites Meet Sustainability: Vol 3 – Characterization* (pp. 358-363). EPFL Lausanne, Composite Construction Laboratory.

# IDENTIFYING MICROSTRUCTURAL FEATURES IN UNIDIRECTIONAL COMPOSITE TAPES

*Nico Katuin[a,b], Daniël Peeters[a] and Clemens Dransfeld[a]*

a: Delft University of Technology, Department of Aerospace Structures and Materials, Delft, The Netherlands – c.a.dransfeld@tudelft.nl

b: Current address: Boikon B.V., Leek, The Netherlands

**Abstract:** *The microstructure of composites has a strong impact on their performance and processability. It influences the structural performance and fatigue life when architected into thin ply composites. The microstructure is also affected by processing conditions, respectively recursively affects processability as observed in the deconsolidation or intimate contact formation during laser assisted tape laying. This work presents a novel approach to identify microstructural features. This is achieved by Voronoi tessellation-based evaluation of the fibre volume content on cross-sectional micrographs, considering the matrix boundary. The method was applied on unidirectional tape samples with characteristic processing history. It is shown to be robust, it is suitable to be automated and has the potential to be expanded into 3d imaging techniques. It offers the possibility to discriminate specific microstructural features and to relate them to processing behaviour.*

**Keywords:** Unidirectional composites; Microstructure; Imaging; Voronoi

## 1. Introduction

Carbon fibre reinforced polymer composites have outstanding properties at low weight. They contribute to the sustainability of air transport, automotive and energy sector. Especially when exploiting their anisotropy in the unidirectional configuration, they outperform most engineering materials in specific stiffness or weight. The engineering and processing properties of unidirectional materials are most commonly derived from homogenization approaches, which assume a perfect regular distribution of the fibre in the matrix. However their processing history, from carbon fibre rovings to finished parts affects their microstructural arrangement and homogeneity. Amacher [1] observed that unidirectional composites, when spread to very thin plies, impact the microstructural homogeneity of the resulting unidirectional laminate resulting in an increase of compression strength of up to 24%. Also in processing, Schuler [2] observed that transverse squeeze flow, an essential behaviour for intimate contact formation [3], is affected by inhomogeneity in fibre distributions. Although the relation between microstructure and resulting properties is undeniable, its correlation has been primarily qualitative.

This work aims to develop quantitative analysis methods for unidirectional composite tapes based on optical cross-sectional microscopy. Using fibre centre identification through image processing, computer vision, and Voronoi tessellation, various quantitative evaluations have been explored and correlated to the processing behaviour.

## 2. Method

The basic approach of cross-sectional microscopy of unidirectional composites has been previously explored by Zangenberg et al. [4]: by identification of fibre centres, a Voronoi tessellation of the cross-section is achieved, where every cell with an area $A_v$ contains an individual fibre with a cross section area $A_f$. We can therefore express the Voronoi-based local fibre volume content $V_{fv}$ at the resolution of a single fibre.

$$\mathrm{V_{fv}} = \frac{\mathrm{A_f}}{\mathrm{A_v}} \tag{1}$$

To process larger microstructures, an adapted, numerically efficient methodology is presented based on the open-source Python library OpenCV [5]. The complete commented code is available on GitHub and archived in Zenodo [6]. Images were taken from embedded samples of carbon fibre unidirectional tapes with a polyaryletherketone matrix. The images were captured with a Keyence VK-X1000 laser scanning confocal microscope in the optical mode using a 50x magnification and coaxial lighting. This corresponded to a pixel resolution of about 1/20th of a fibre diameter. Using the embedded stitching capability, images with 17000 x 700 pixels of large tape cross-sections were assembled.

The image processing consisted of four main steps : (1) fibre centre detection, (2) identification of individual fibre diameters, (3) detection of the outer boundary, followed by (4) Voronoi tesselation taking into account these boundaries.

The images were processed through mean shift segmentation, blurring and thresholding (*Figure 1*). Applying Euclidian distance mapping in combination with an 8-connectivity watershed allowed to discriminate individual fibres, also in densely packed situations, as seen in *Figure 2*. Furthermore, proximity analysis based on the nominal fibre diameter allowed to merge overlapping interpretations.

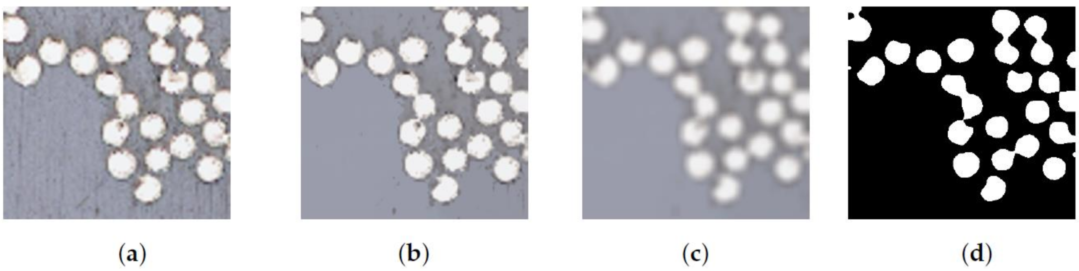



*Figure 1. Image processing steps (a) original, (b) mean shift segmentation, (c) blurring, (d) thresholding, (from [7])*

Based on previously computed fibre centres, the fibre radius was determined in four directions based on greyscale thresholding as illustrated in Figure 3. Other authors use the circle Hough Transform [8] for the fibre centre and fibre diameter feature extraction, which comes, compared to this method, at high cost of computation and storage compared to the presented methods.

The outmost Voronoi cells of a finite number of fibre centres have, per definition, an infinite size; therefore, the matrix boundary of the tape sample was digitized into a polygon to cap the perimeter Voronoi cells (Figure 4) for dedicated analyses.

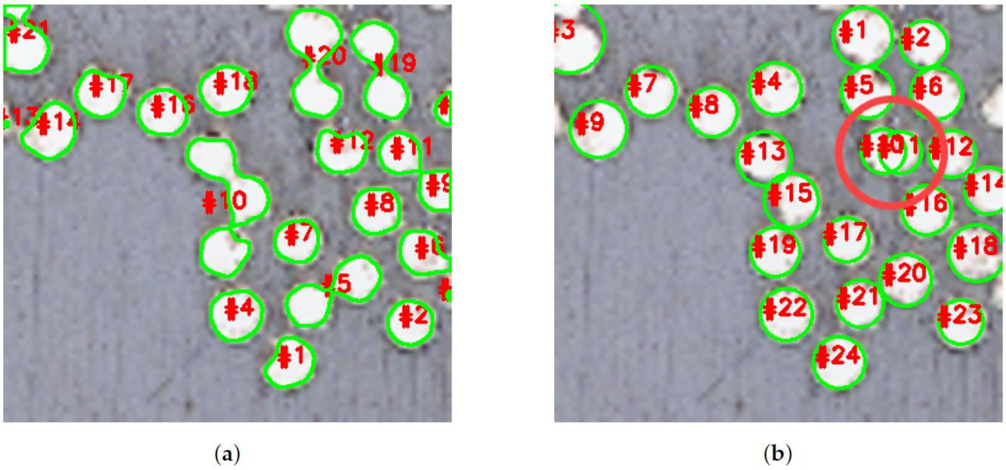



*Figure 2. Definition of fibre contours (a) without and (b) with 8-connectivity watershed, (from [7])*

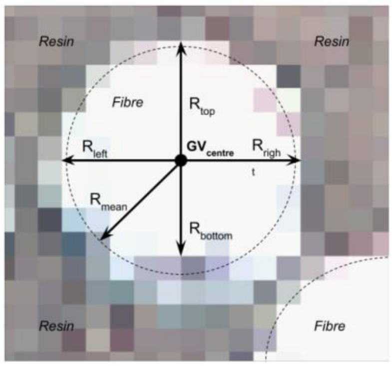



*Figure 3. Definition of mean fibre radius based on grey scale evaluation in 4 directions (from [7])*

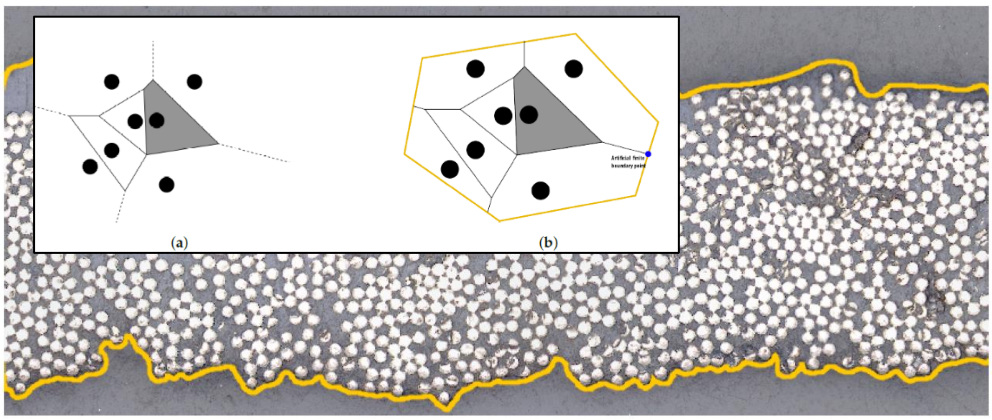
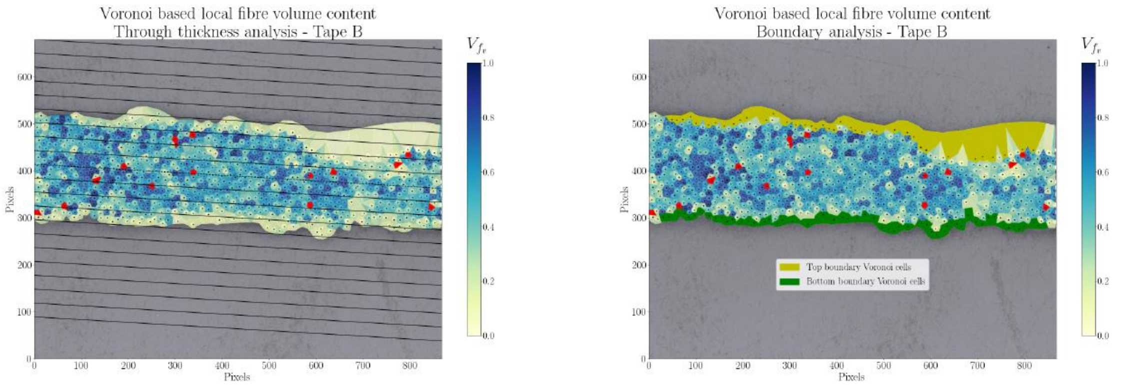



*Figure 4. Tape boundary represented as polygon, trimming the infinite boundary Voronoi cells (a) to finite size (b) (from [7], modified)*

## 3. Results

To assess the method, three unidirectional tapes, further referred to as A, B and C, made with different spreading and impregnation techniques [9, 10] were imaged, segmented and analysed. Next to analysing the fibre volume content over the entire cross-section, the $V_{fv}$ was also homogenized for a through thickness evaluation and for dedicated analysis of the outmost upper and lower boundary elements, as illustrated in Figure 5. In some cases, in highly compacted areas, due to imaging inaccuracies, the evaluation of $V_{fv}$ could yield values greater than one, when $A_f \geq A_v$. These cells were flagged red for clarity and removed from the analyis.




(a) (b)

*Figure 5. (a) Through thickness segmentation of tape in about 8-10 segments, (b) identification of top and bottom surface cells for specific analyses, (example from tape B, taken from [7])*

The $V_{fv}$ plots of the different tapes shown in *Figure 6* to *Figure 8* reveal distinct differences between the different tapes. The through-thickness analyses shown in *Figure 9*, reveal distinct edge-core morphologies for tape A and B. This is also confirmed in the histograms shown in Figure 10, again tapes A and B show contrasting $V_{fv}$ distributions at the surface in terms of median and skewness.

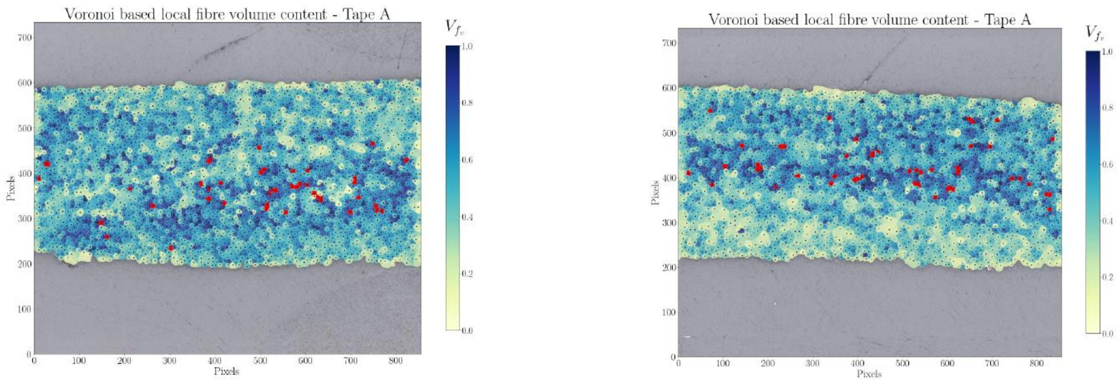



*Figure 6. $V_{fv}$ analyses of two characteristic sections from tape A [7]*

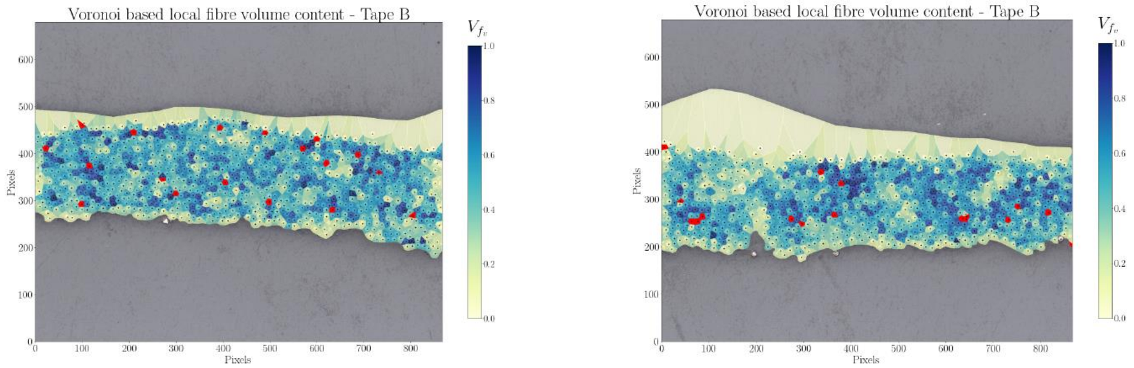



*Figure 7. $V_{fv}$ analyses of two characteristic sections from tape B [7]*

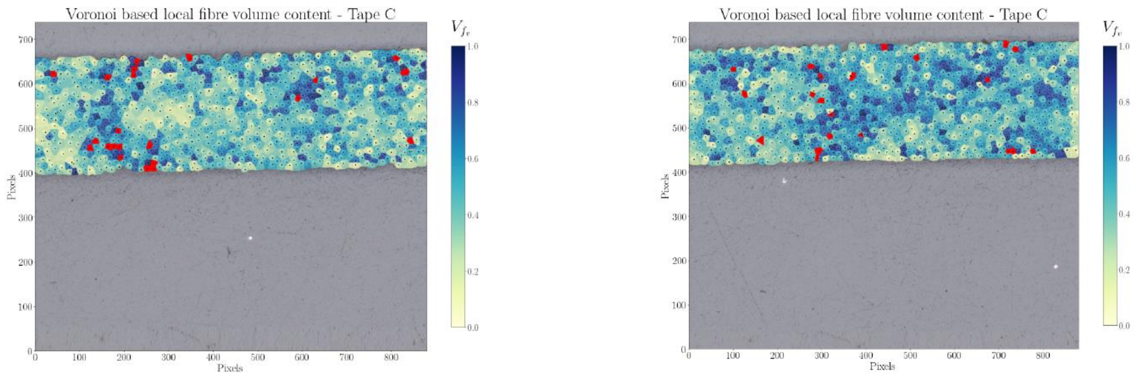



*Figure 8. $V_{fv}$ analyses of two characteristic sections from tape C [7]*

## 4. Conclusion

This work presents a novel approach to identifying microstructural features, based on single fibre identification in cross-sectional micrographs, considering the matrix boundary. The authors have investigated the robustness of the methods in depth [7]. The methods reveal characteristic microstructural features of the fibre distribution, which can be further spatially or statistically quantified and related to processing properties. Ultimately, these can be expanded to the 3rd dimension and will serve to develop representative volume elements. The observation of tape manufacturing-related edge core effects does also relate to other microstructural features of the fibre architecture, which has recently been confirmed by Gomarasca et al [11].

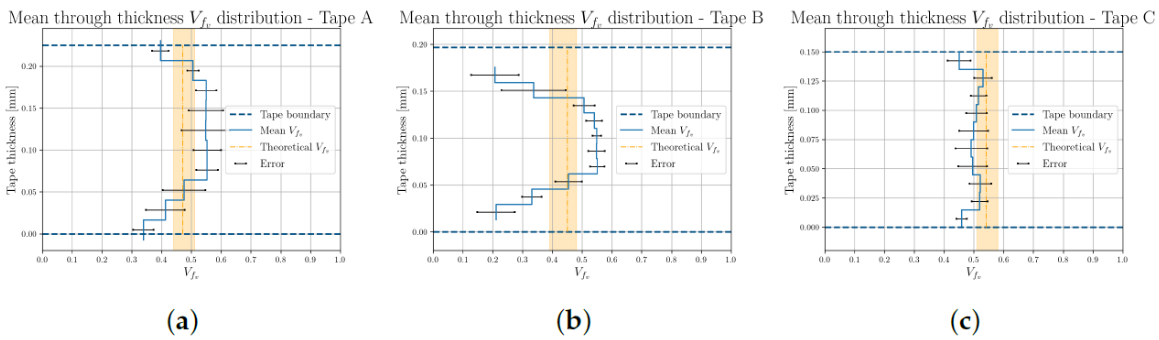
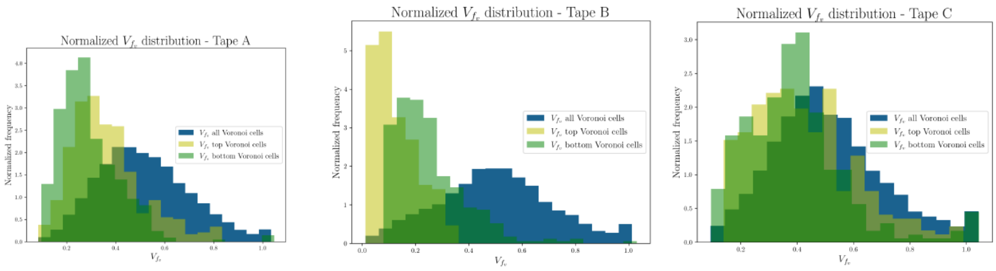



*Figure 9. Through thickness evolution of $V_{fv}$ for tapes A, B and C (from [7])*




(a) (b) (c)

*Figure 10. $V_{fv}$ for the entire tape compared to the top and bottom surface for tapes A, B and C (from [7])*

## 5. References


[1] R. Amacher, J. Cugnoni, J. Botsis, L. Sorensen, W. Smith, and C. Dransfeld, "Thin ply composites: Experimental characterization and modeling of size-effects," *Composites Science and Technology,* vol. 101, no. 0, pp. 121-132, 9/12/ 2014.

[2] S. F. Shuler and S. G. Advani, "Transverse squeeze flow of concentrated aligned fibers in viscous fluids," *Journal of Non-Newtonian Fluid Mechanics,* vol. 65, no. 1, pp. 47-74, 1996/07/01/ 1996.

[3] O. Çelik, D. Peeters, C. Dransfeld, and J. Teuwen, "Intimate contact development during laser assisted fiber placement: Microstructure and effect of process parameters," *Composites Part A: Applied Science and Manufacturing,* vol. 134, p. 105888, 2020/07/01/ 2020.

[4] J. Zangenberg, J. B. Larsen, R. C. Østergaard, and P. Brøndsted, "Methodology for characterisation of glass fibre composite architecture," *Plastics, Rubber and Composites,* Conference Paper vol. 41, no. 4-5, pp. 187-193, 2012.

[5] G. Bradski and A. Kaehler, *Learning OpenCV: Computer vision with the OpenCV library*. " O'Reilly Media, Inc.", 2008.

[6] N. Katuin and C. Dransfeld, "UD Microstructural characterisation," no. v1.0. doi: 10.5281/zenodo.5517774

[7] N. Katuin, D. M. J. Peeters, and C. A. Dransfeld, "Method for the Microstructural Characterisation of Unidirectional Composite Tapes," *Journal of Composites Science,* vol. 5, no. 10, p. 275, 2021.

[8] J. Illingworth and J. Kittler, "A survey of the hough transform," *Computer Vision, Graphics, and Image Processing,* vol. 44, no. 1, pp. 87-116, 1988/10/01/ 1988.

[9] K. K. C. Ho, S. R. Shamsuddin, S. Riaz, S. Lamorinere, M. Q. Tran, A. Javaid, and A. Bismarck, "Wet impregnation as route to unidirectional carbon fibre reinforced thermoplastic composites manufacturing," *Plastics, Rubber and Composites,* vol. 40, no. 2, pp. 100-107, 2011/03/01 2011.

[10] C. Hopmann, E. Wilms, C. Beste, D. Schneider, K. Fischer, and S. Stender, "Investigation of the influence of melt-impregnation parameters on the morphology of thermoplastic UD-tapes and a method for quantifying the same," *Journal of Thermoplastic Composite Materials,* p. 0892705719864624, 2019.

[11] S. Gomarasca, D. M. J. Peeters, B. Atli-Veltin, and C. Dransfeld, "Characterising microstructural organisation in unidirectional composites," *Composites Science and Technology,* vol. 215, p. 109030, 2021/10/20/ 2021.